

THERMAL ANNEALING OF RADIATION DAMAGED SILICON - I. ELECTRON RADIATION

by

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We have observed a complete recovery of Silicon solar cells damaged by electron or proton radiation at room temperature by thermal annealing. The technological aspects of these results are very interesting because we can visualize the possibility of rejuvenating solar cells on satellites which have been damaged by space radiation. The purpose of this letter is to report some observations associated with the kinetics of defect annealing in Silicon which have basic physical interest.

In our experiment, the so-called n-on-p solar cells were used. The front surface of the cell, where the light enters, consists of n-type (P-doped) Silicon, about 0.5μ thick. Under this is an n-p junction of about 0.5μ thickness followed by a thick p-layer (B-doped) Silicon of about 500μ thickness. The electrodes are Ag-Ti alloy. The isothermal annealing is conducted in a hydrogen atmosphere to avoid the oxidation of the electrodes.

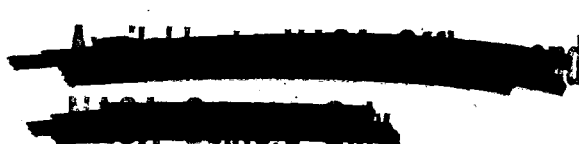
Figure 1(a) illustrates a histogram of a typical quantum yield (Q.Y.) curve. The base material of this solar cell has 10Ω -cm resistivity. The curves indicate a profound change of the quantum yield at wavelengths longer than 0.6μ corresponding to a depth greater than 3μ , i.e., in the p-region. However, one cannot infer a lesser damage susceptibility in the n-region. The appearance of this lesser damage is due to the p-n junction field which is very near to the n-region. We are continuing

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the work with p-on-n type solar cells to facilitate the comparison and the interpretation. The histogram illustrates that the damage introduced by 4×10^{14} electrons/cm² of 1 Mev energy, corresponding to an overall degradation of 20% efficiency, can be completely annealed by heating at 400°C for 15 minutes. In Figure 1(a), the results even indicate an improvement of the overall quantum yield of the annealed specimen compared to the original values. This effect is small, but is not a rare case.

Figure 1(b) gives the change of Q.Y. from the original value, that is, $1 - (Q.Y.)_{\phi} / (Q.Y.)_0$, due to the radiation of 1 Mev electrons at three different accumulated flux levels ϕ and consequent annealings measured at 0.9 μ (with 100Å bandwidth). The results cannot be explained by an intuitive picture that the number of annealed defects is proportional to the original number of defects, as in the model of a radioactive mass decay. According to this model, larger annealing effects should be observed in high defect density specimens. Figure 2 indicates the opposite. We would like to emphasize that our observations in this case were made with almost monochromatic light. Therefore, spatial dispersion effects in the different regions of the cells connected with optical absorption coefficients, as would be found with the composite spectra of an artificial light source are considerably reduced.

Figure 2 shows the recovery of the short circuit current. The light source is a Xenon arc. The curves indicate an initial fast recovery stage, plus a slower stage or stages of recovery. Therefore, a single first or second order kinetics is not adequate to describe the observation. This is in agreement with the conclusion of Brown et al. and demands a proposal of more than one kind of defect.



A strong dependence of the annealing kinetics on the flux level is also indicated in Figure 2. If we shift the origins of the time axis for curves of different original damage, and if there is no interaction among different defects, then the consideration of the thermal equilibrium of defects at specific temperatures, and the similarity of the rate of introduction and annealing ⁽¹⁾ demands a coalescence of all curves. That is, all curves with different prior histories of damage, but reduced to identical values through thermal annealing should follow the same annealing kinetics thereafter. The observation of the opposite result supports an interaction mechanism.

We have also measured thermal annealing for solar cells of various base resistivities, and observed a comparative difficulty in annealing specimens with low base resistivity. This is opposite to the behavior of the dependence of the radiation damage on the base resistivity, and implies the importance of the Fermi level on the radiation damage.

The results of the thermal annealing of proton damage is much different from that of electron damage, especially in the annealing temperatures and activation energies. This phase will be reported in an ensuing letter.

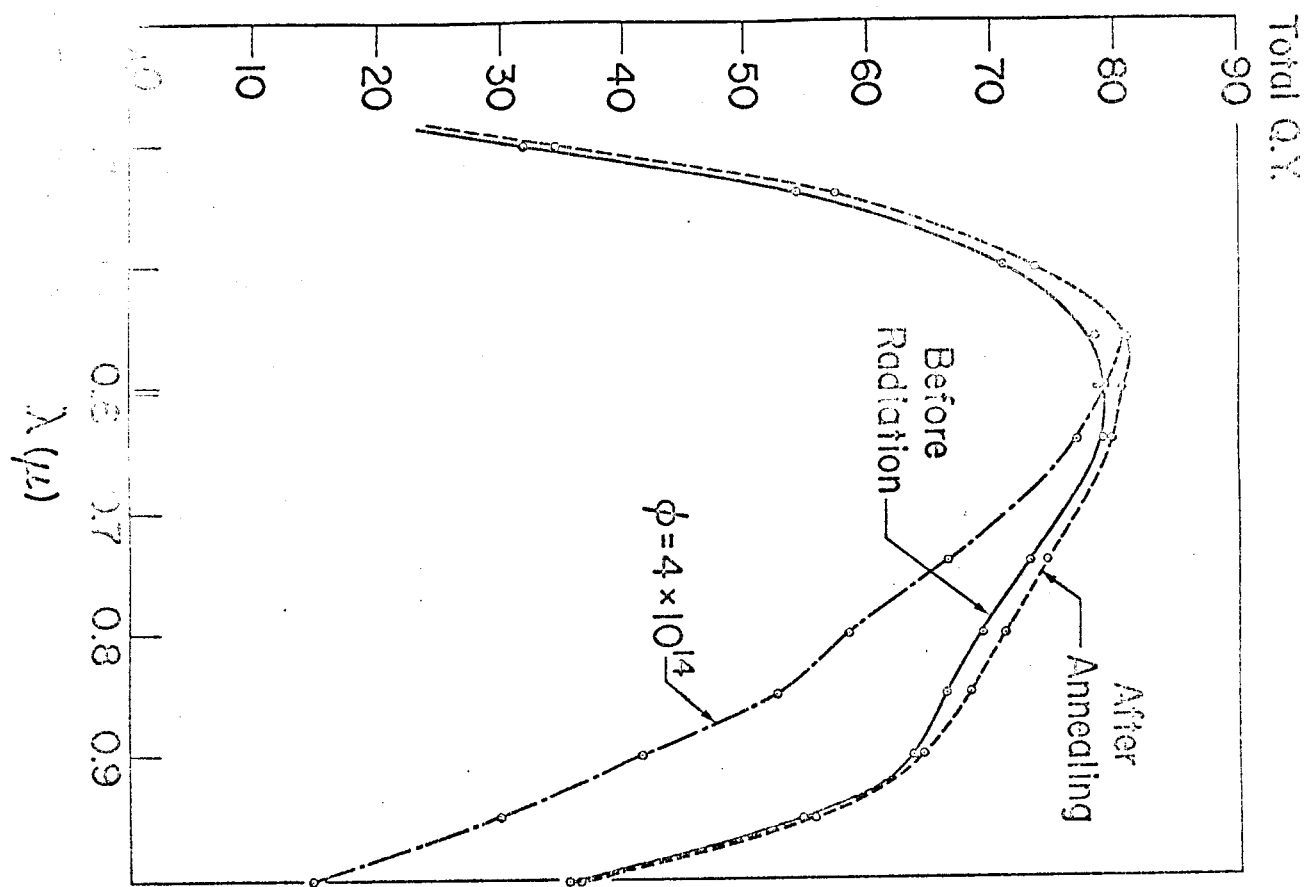
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References

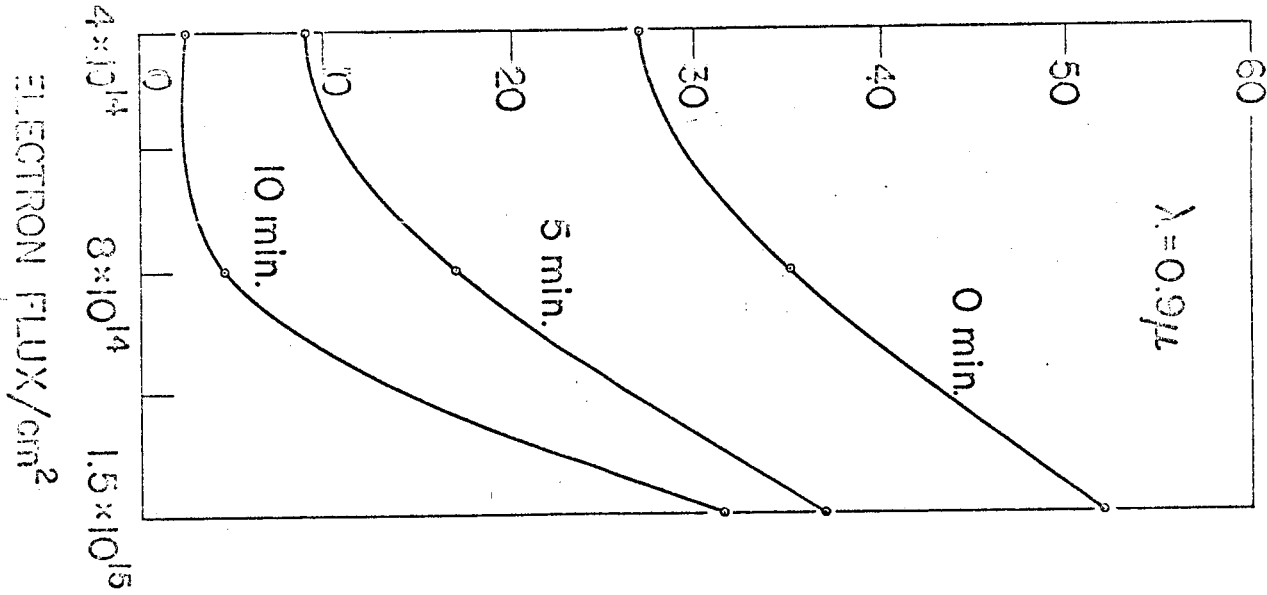
1. Brown, Augustyniak, and Waite, J. Appl. Phys. 30, 1258 (1959).

List of Figures

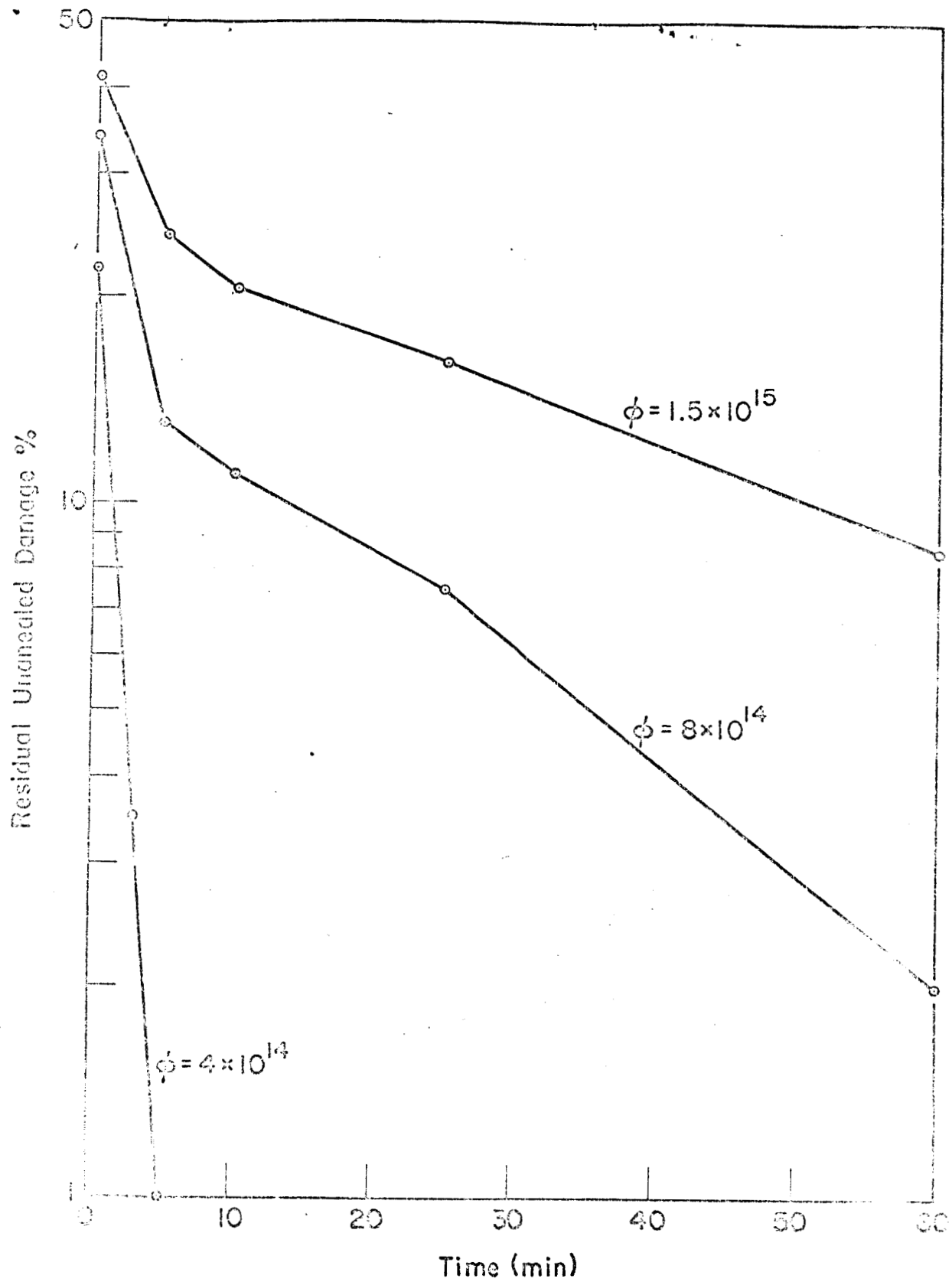
- Figure 1(a) - Total quantum yield spectra of a solar cell, original, after radiation and after annealing.
- 1(b) - Successive stage of annealing at 400°C for different level of damages.
- Figure 2 - Isothermal (440°C) annealing curve for three levels of damage.



Degradation of Q.Y. (Percent)



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